Treatment planning for Carbon ions (II)

PTCOG 43 Educational Satellite Meeting

Darmstadt 2005

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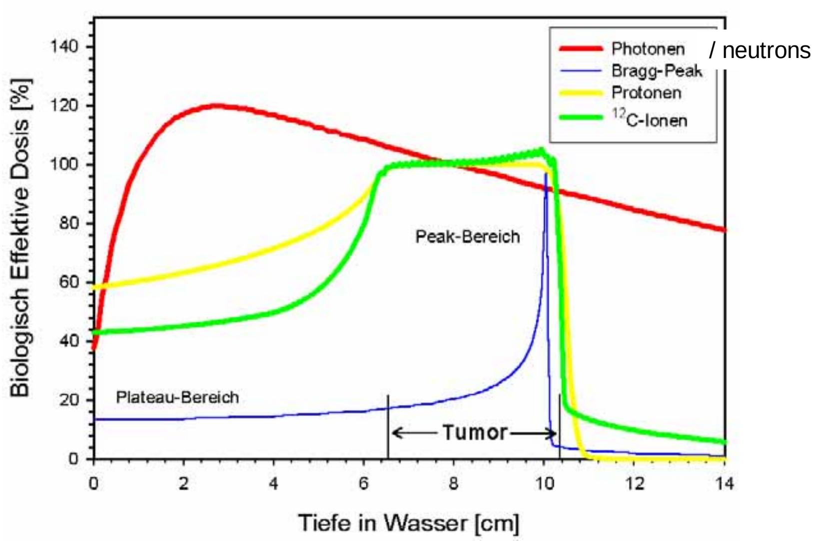
GERMAN CANCER RESEARCH CENTER IN THE HELMHOLTZ ASSOCIATION

Depth dose distributions of Hadron beams

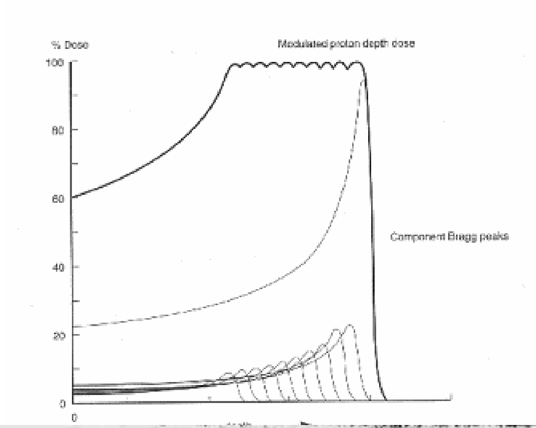


- Neutrons are very similar to photons in terms of depth dose
- Ions show reduced entrance dose
- No / little dose behind the tumor

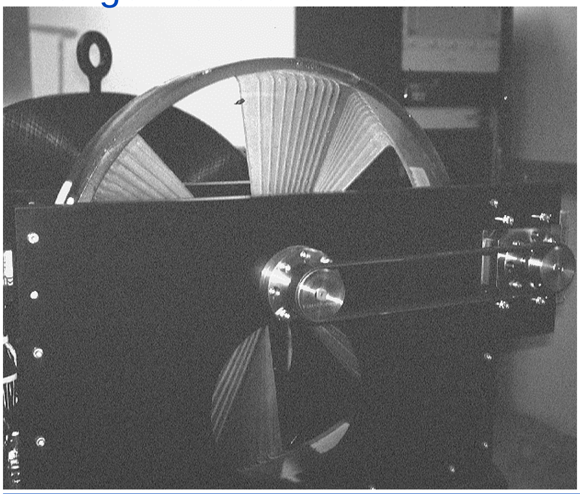
Passive beam shaping

A) Shaping of the depth dose (SOBP):

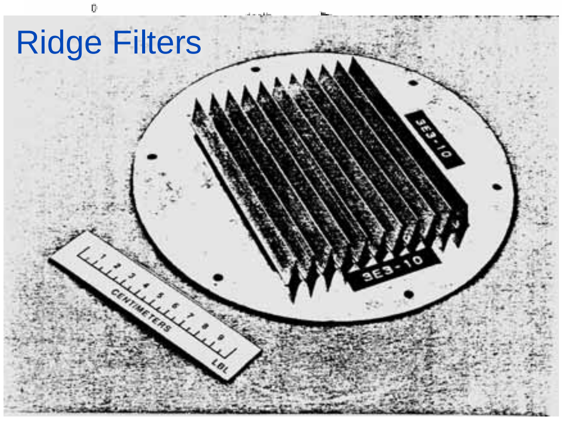
$$D(z) = \sum_{i=1}^{n} w_i D_i(z)$$



Range modulator wheel



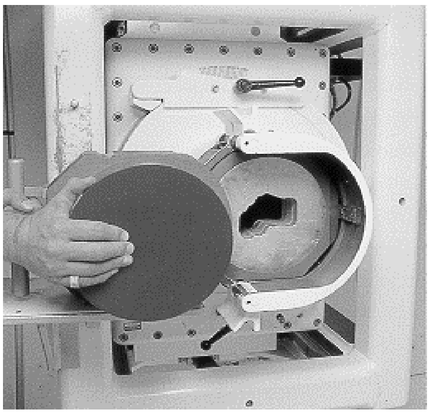
Ridge Filters



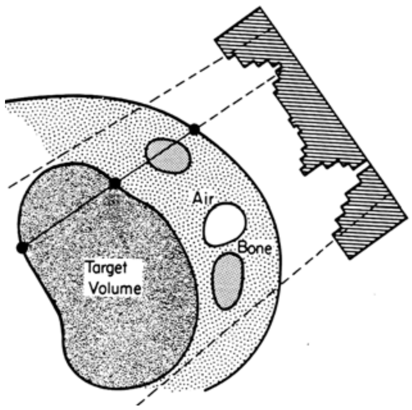
Passive beam shaping

B) Patient specific hardware for beam shaping

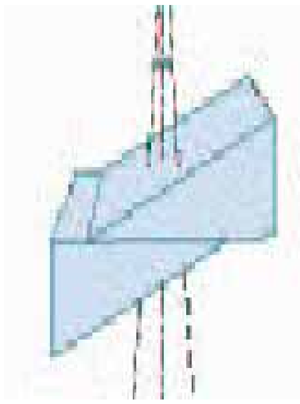
Collimator



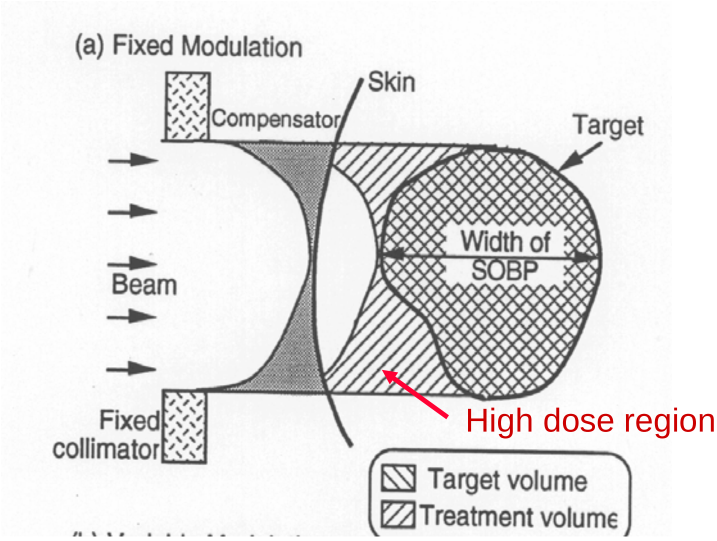
Compensator



Range shifter



TPS for passive beam shaping



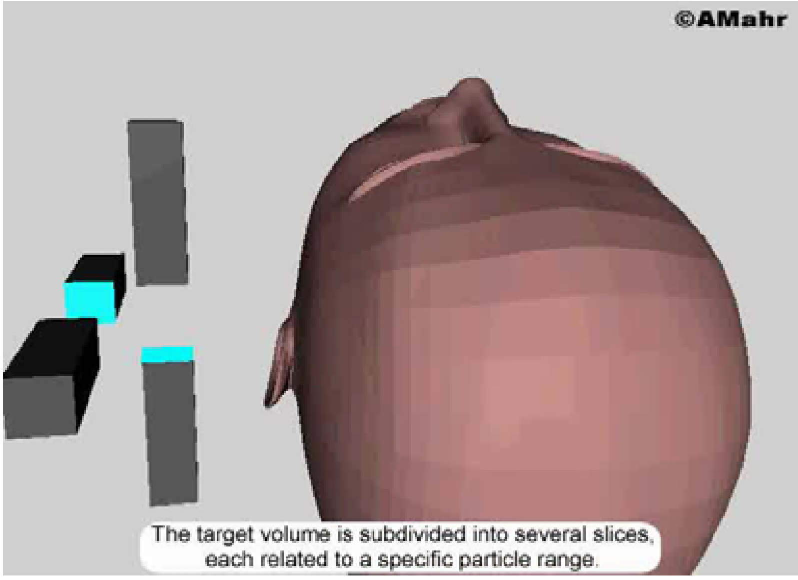
SOBP has a fixed extension

Dose conformation only at distal end

- Only measured depth doses needed
- No detailed biological modeling needed

3D Active beam scanning at GSI

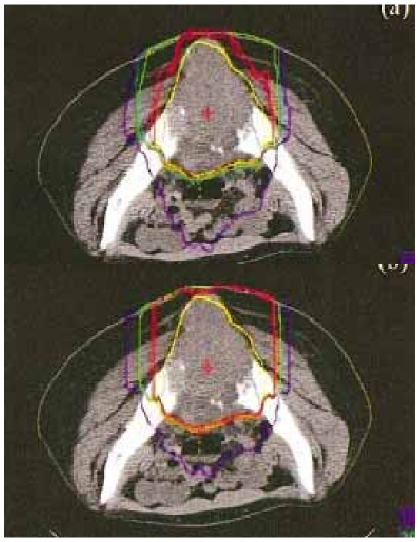
- Energy variation of synchrotron (~1mm resolution depth)
- Intensity controlled raster scanning (~2 mm, 5mm fwhm)

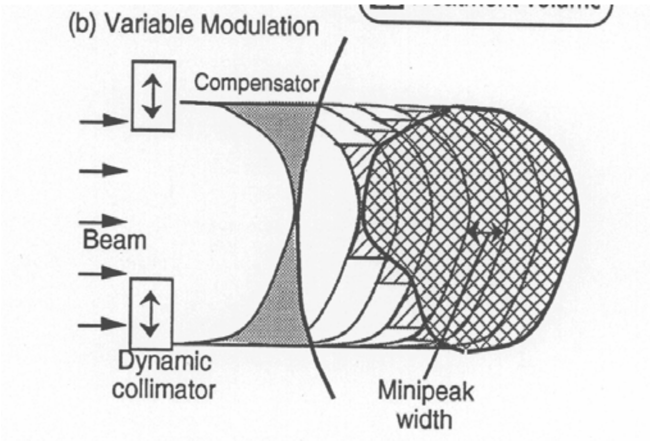


Optimization of typically 30-50 energies, 20000 -50000 field spots

3D active beam shaping (protons: PSI, ions: GSI)

- No patient specific hardware
- Fragmentation model needed
- Biological modeling needed



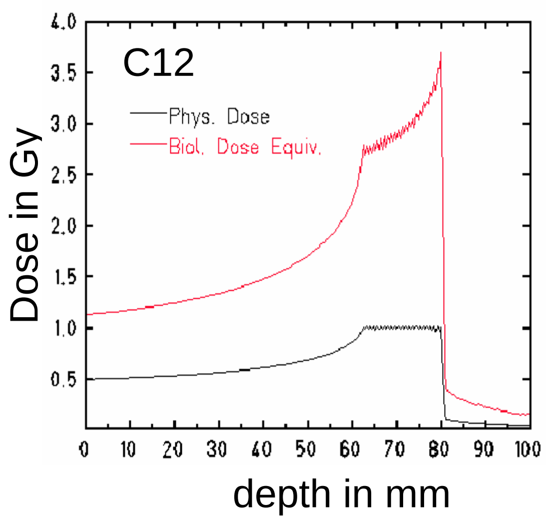


Single Bragg peaks
Variable energy
Scanning or MLC

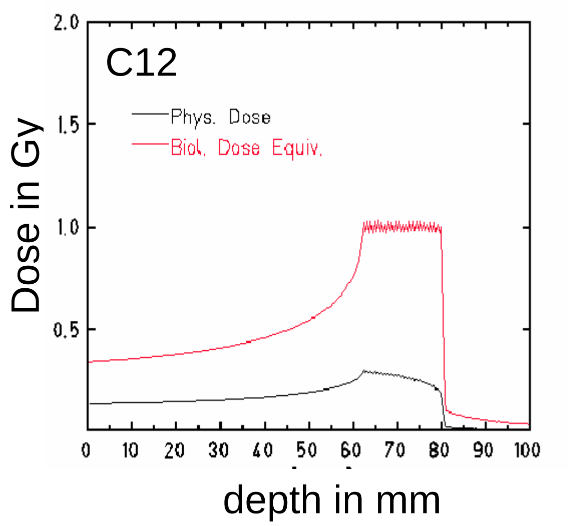
Dose conformation also at proximal end

Calculation of biological effective dose for ions

Physical dose optimization



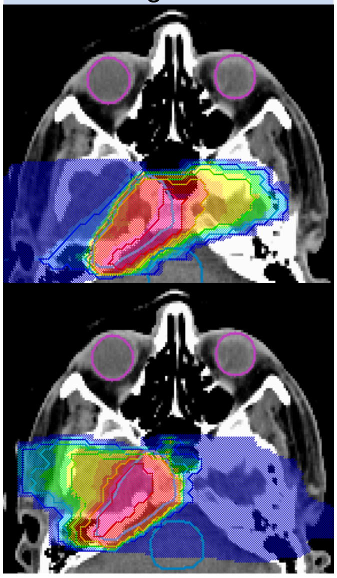
Biological dose optimization



- Account for nuclear fragmentation in every point in 3D
- Detailed biological modeling necessary

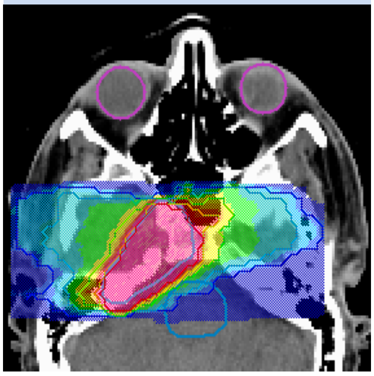
Biological treatment planning for carbon ions

Physical dose of single fields

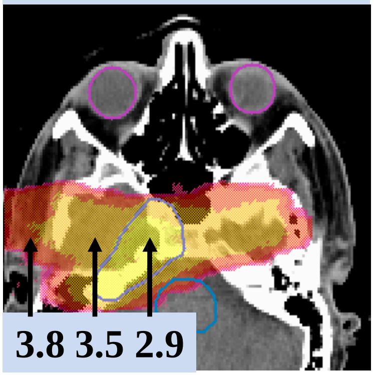


Local effect model of Scholz and Kraft:
Calculation of RBE as a 3D distribution
Input: X-ray survival curves & fragmentation spectra

Biological effective dose



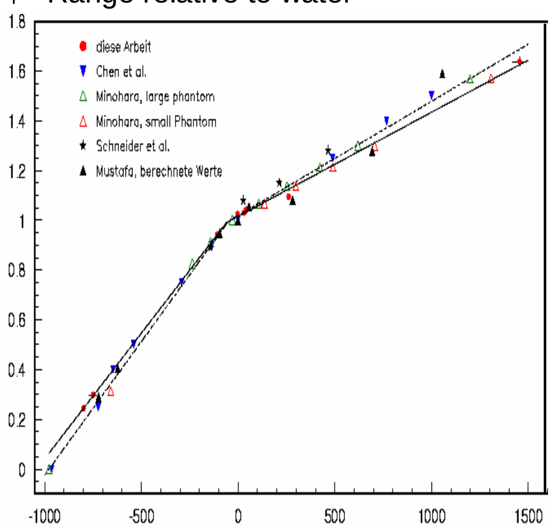
RBE-distribution



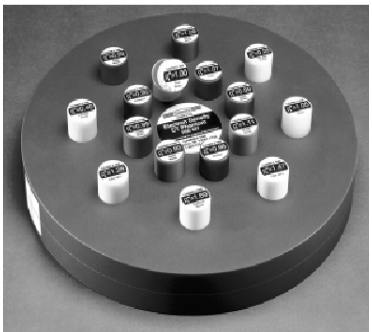
Empirical range calculation from CT numbers

- Tissue equivalent phantoms
- Real tissue measurements

Range relative to water

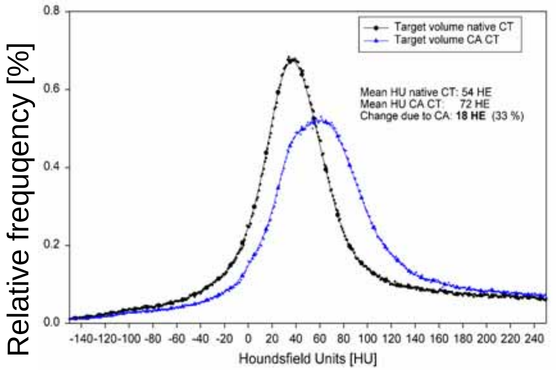


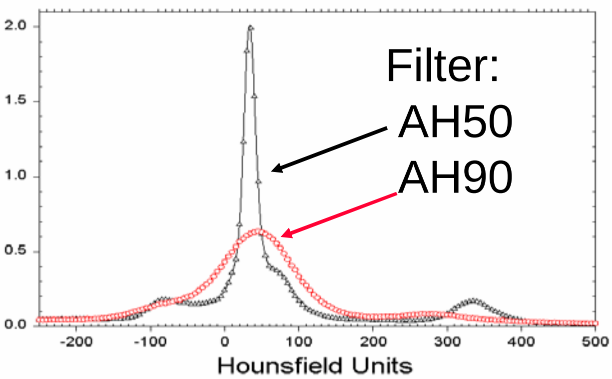
CT number



Uncertainty of range is ~2mm for the head region

Possible distortions of CT numbers



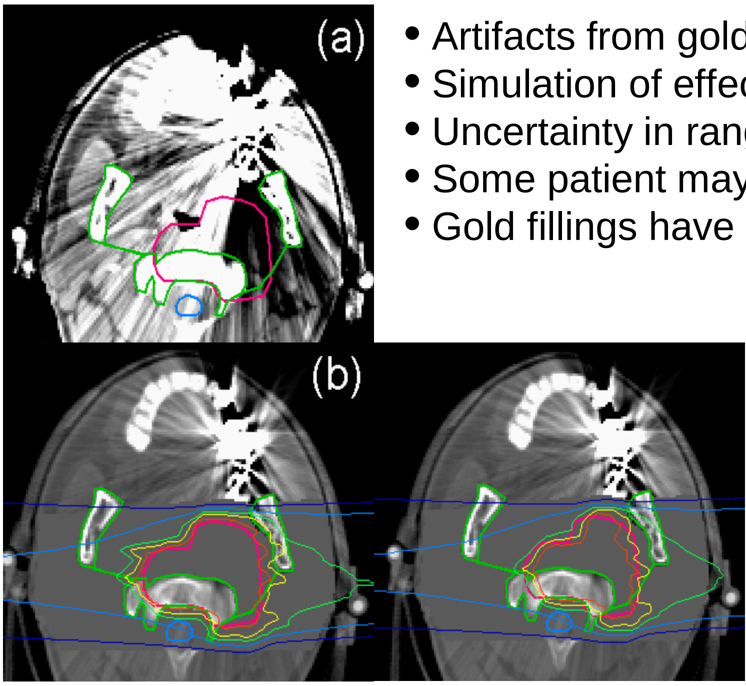


Contrast agent in CT
- mean shift (25 pat.): 18 HU
- max shifts: 36 HU
- Errors in range < 1.6 %

Reconstruction filters
- redistribution of HU numbers
- Errors in range < 3 %

Special attention to QA of the CT and imaging protocols !

Metal artifacts in CT images

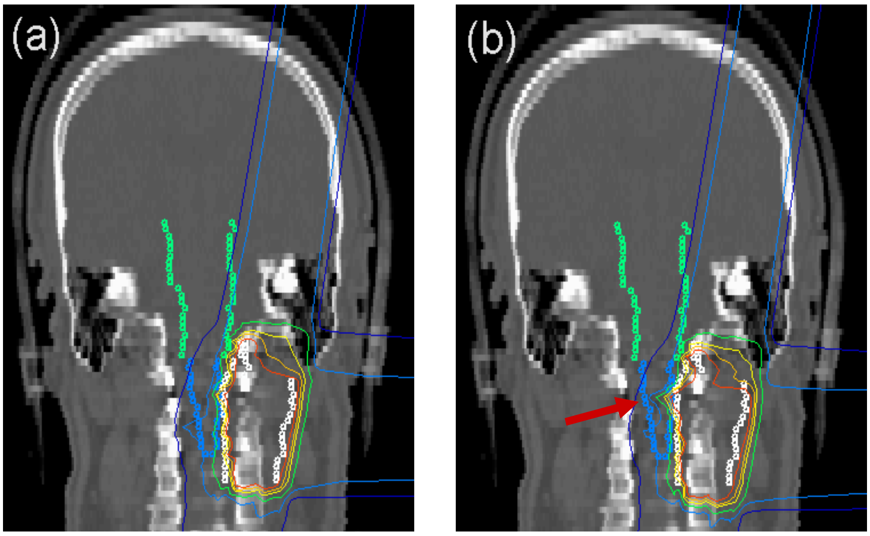


- Artifacts from gold fillings or implants
- Simulation of effects of wrong HU
- Uncertainty in range calculation
- Some patient may be rejected
- Gold fillings have to be removed

Uncertainties in Range due to misalignment

Wrong patient position changes the tissue traversed by the beam and may lead to over/underdosages:

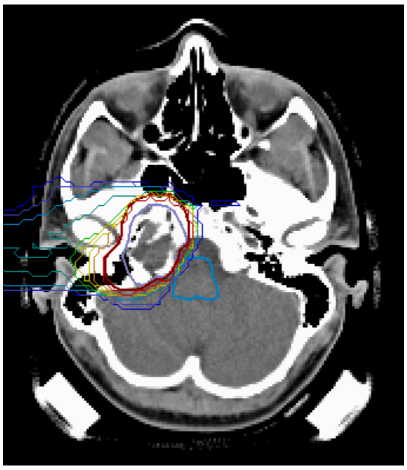
Effect of a 5mm cranial shift on the particle ranges:



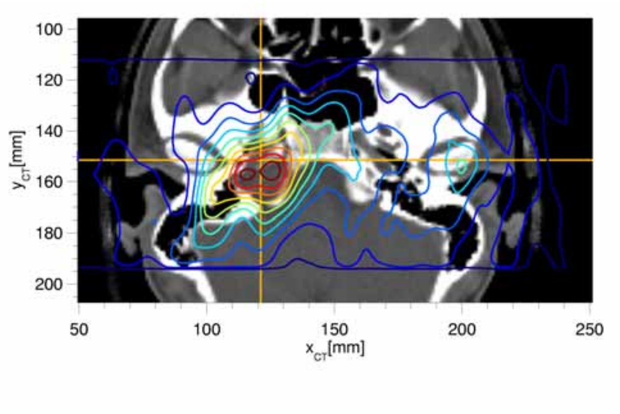
The robustness of treatment plans has to be tested!

PET – Monitoring in situ

Patient with Chondrosarcoma of skull base



Dose distribution carbon ions

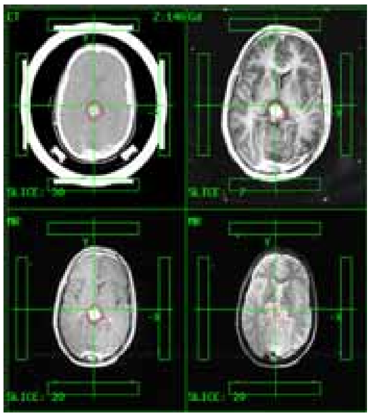


PET-Measurement

In vivo range verification!
PET or Cone beam CT for IGRT ?

Patient fixation and positioning for ion therapy

X-ray CT MRI 3d Turbo FLASH



MRI epin-echo MRI T2 spin echo

- Multimodal imaging and image correlation
- Stereotactic positioning techniques

- High precision fixation techniques

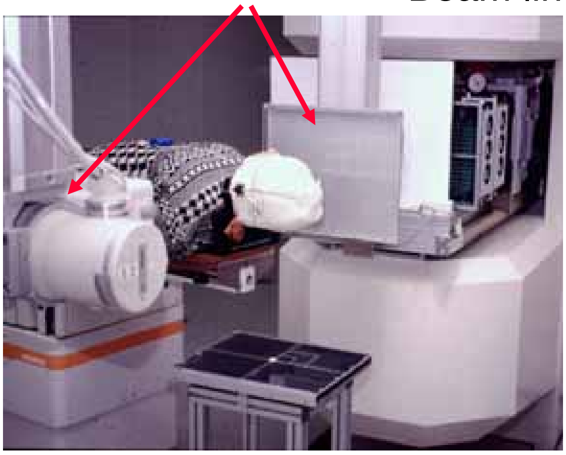
Patient setup and treatment at the German heavy ion facility GSI

Fixed beam line, no gantry

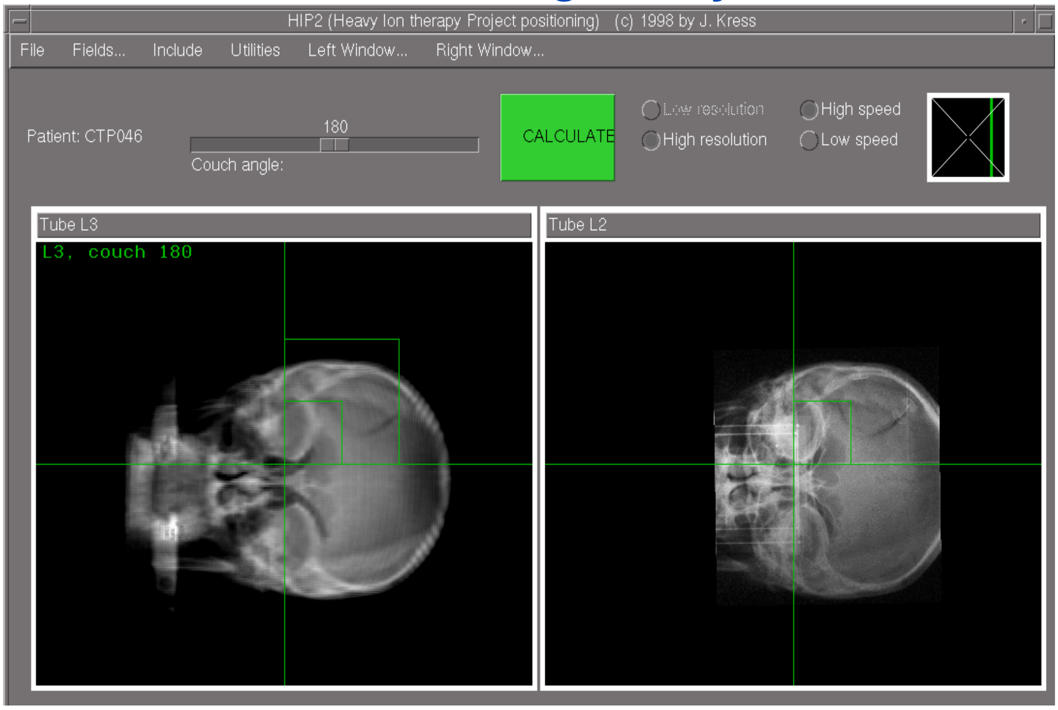
PET-camera

X-ray system

Beam line



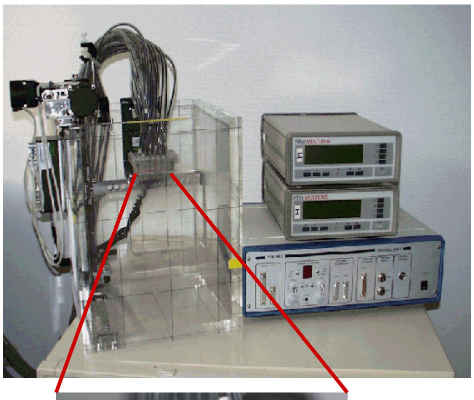
Position control using X-rays and DRR



Accuracy for positioning of bones of ~ 1mm can be achieved

Dose verification for active beam delivery

Problem:
- Scanning chambers for dynamic fields not suitable
- Simultaneous measurement of many channels

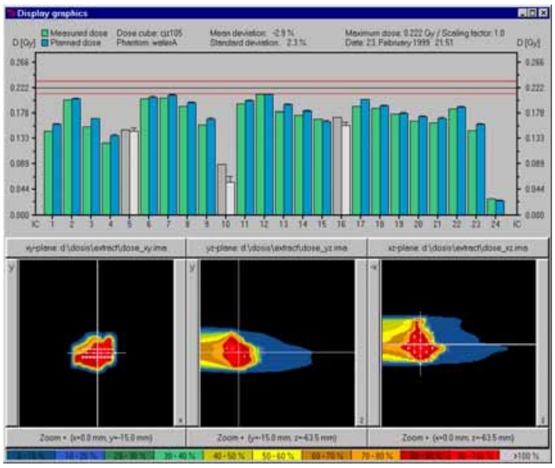


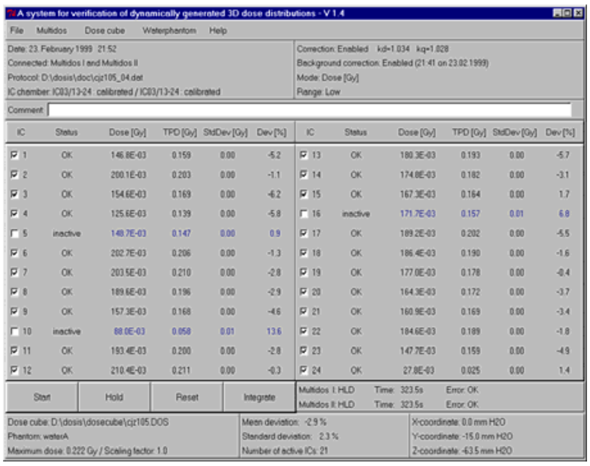
Verification phantom:
- 24 Pinpoint chambers
- Readout by 2 Multidos-Dosemeters
- Computer controlled movement of the chambers in the water phantom

Verification software

- Interface to therapy planning
- Display dose in water
- Display of chamber positions

- Measurement at 24 positions
- Comparison w. therapy planning
- Analysis and documentation



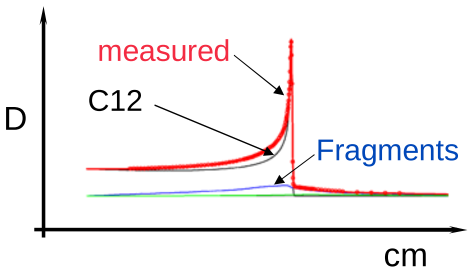


Verification of therapy plans prior to first application

Carbon Ion Dose Determination

$k_{Q,Qo}$ concept of IAEA TRS-398

$$k_{Q,Q_o} = \frac{\left(W_{air}/e\right)^{^{12}C}}{\left(W_{air}/e\right)^{^{60}Co}} \cdot \frac{\bar{s}^{^{12}C}_{w,air}}{\left(\bar{L}/\rho\right)^{^{60}Co}_{w,air}} \cdot \frac{p^{^{12}C}}{p^{^{60}Co}}$$



Spencer-Attix Stopping Power Ratio

$$\bar{s}_{w,air} = \frac{\sum_i \int_0^\infty \Phi_{E,i} (S_i(E)/\rho)_w \, dE}{\sum_i \int_0^\infty \Phi_{E,i} (S_i(E)/\rho)_{air} \, dE}$$

Parameter	$(w/e)^{^{12}C}$	$(w/e)^{^{60}Co}$	$s^{^{12}C}_{w,air}$	$(\bar{L}/\rho)^{^{60}Co}_{w,air}$	$p^{^{60}Co}$	$p^{^{12}C}$
Uncertainty	1.5 - 4%	0.2%	2.0%	0.5%	0.6%	1%?

Indications treated with carbon ions at GSI

Skull base chordoma and chondrosarcoma

Fully fractionated therapy, 60 Gye in 20 fractions
8/98 - 12/01: 67 patients treated in phase I/II studies
since 3/02: approval to use HIRT as standard therapy (~55 pat.)

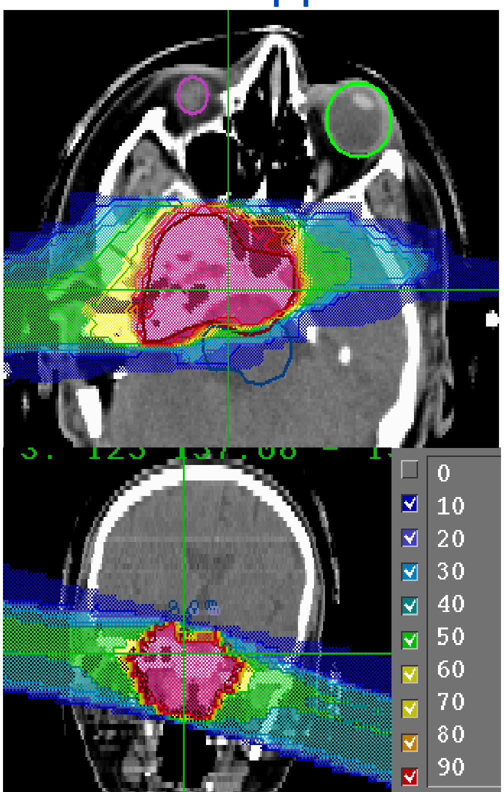
Adenoidcystic Carcinoma and atypical meningeoma

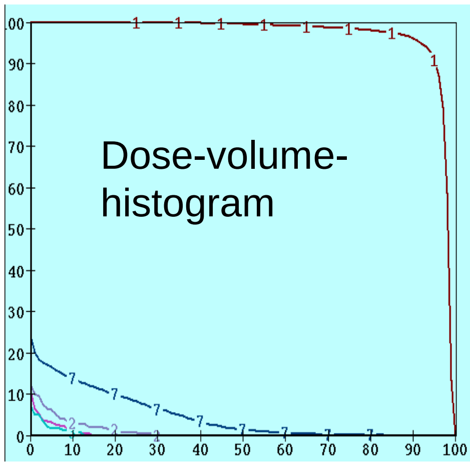
Carbon ion boost after conventional therapy or IMRT
18 Gye in 6 fractions HI + 54 Gy photons
3/00 - 8/04: ~45 patients in phase I/II studies

Pelvic and spinal chordoma and chondrosarcoma

Carbon ion boost after conventional therapy or IMRT
18 Gye in 6 fractions HI + 54 Gy photons
6/00 - 8/04: ~22 patients in phase I/II studies

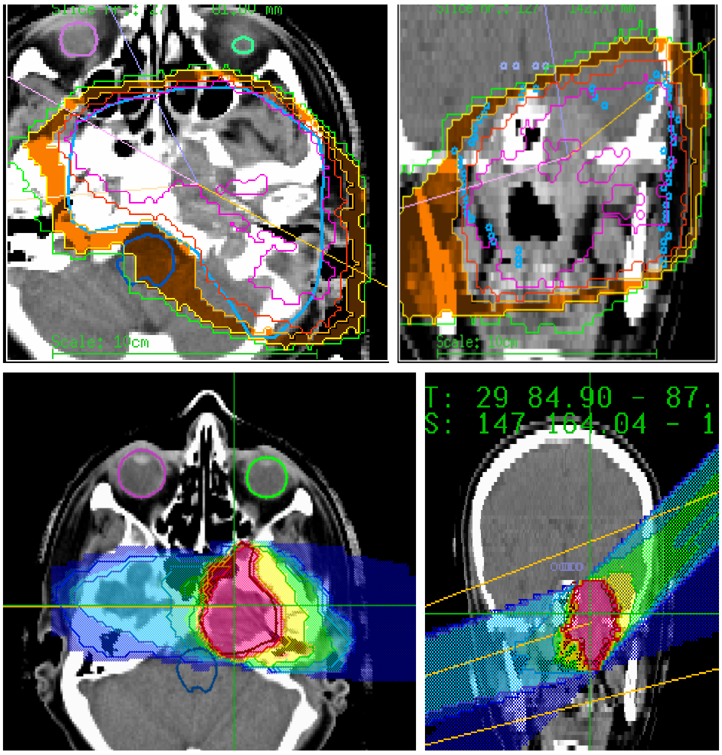
Clinical application: Skull base tumor





Primary Ion therapy
2 Fields
60 Gye in 20 Fractions

Combination Therapy for Adenoidcystic Ca.



Fractionated radiotherapy with photons to 54 Gy to PTV

Boost treatment with carbon ions 18 Gy to GTV

Rationale:
- Normal tissue in PTV
- More robust plans
- More patients treated

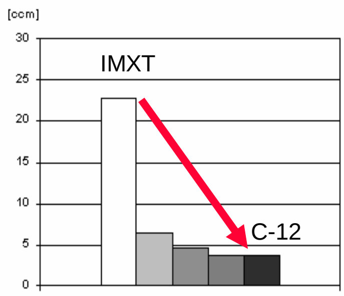
IMXT vs. Carbon ions for spinal chordoma

Schulz-Ertner et al. PMB 48, 2003

- C-12 RT plan and IMXT plan for 1 patient
- total dose: 60 Gye (PTV)
- different ratios of IMXT / C-12 dose: 40:20, 30:30, 20:40
- DVH analysis of dose distributions

Results:
- Very good sparing of spinal chord for all plans
- Best target coverage with C12 alone
- C-12 treatment more subject to setup errors !
- 84 % reduction of V_{50Gye} for C12 vs IMXT:

Volume of normal tissue Irradiated with 50 Gye

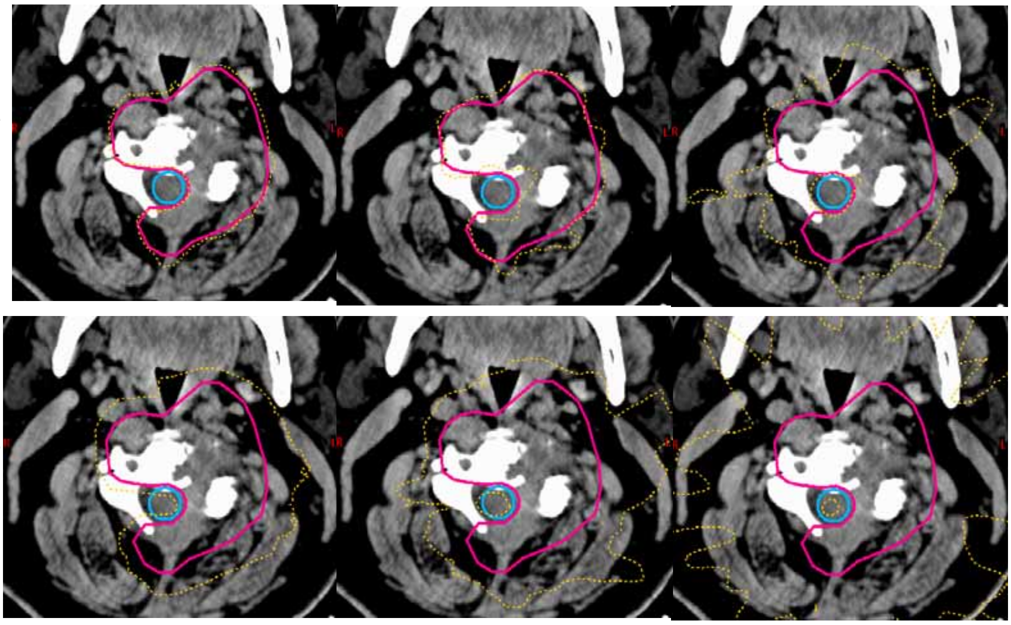


IMXT and/or Carbon ions for spinal chordoma

60 Gye C-12 | 40 +20 Gye (IMXT + C-12 | 60 Gye IMXT

90% isodose

50% isodose



Reduction of integral dose + safe treatment (misalignment) using IMRT (40Gye) + C12-boost (20Gye)

Proton/Ion Facility in Heidelberg

- compact heavy ion synchrotron
- Isocentric scanning gantry for ions
- p,He,C,O,... ions
- 1000 patients/yr
- In operation ~2006/2007